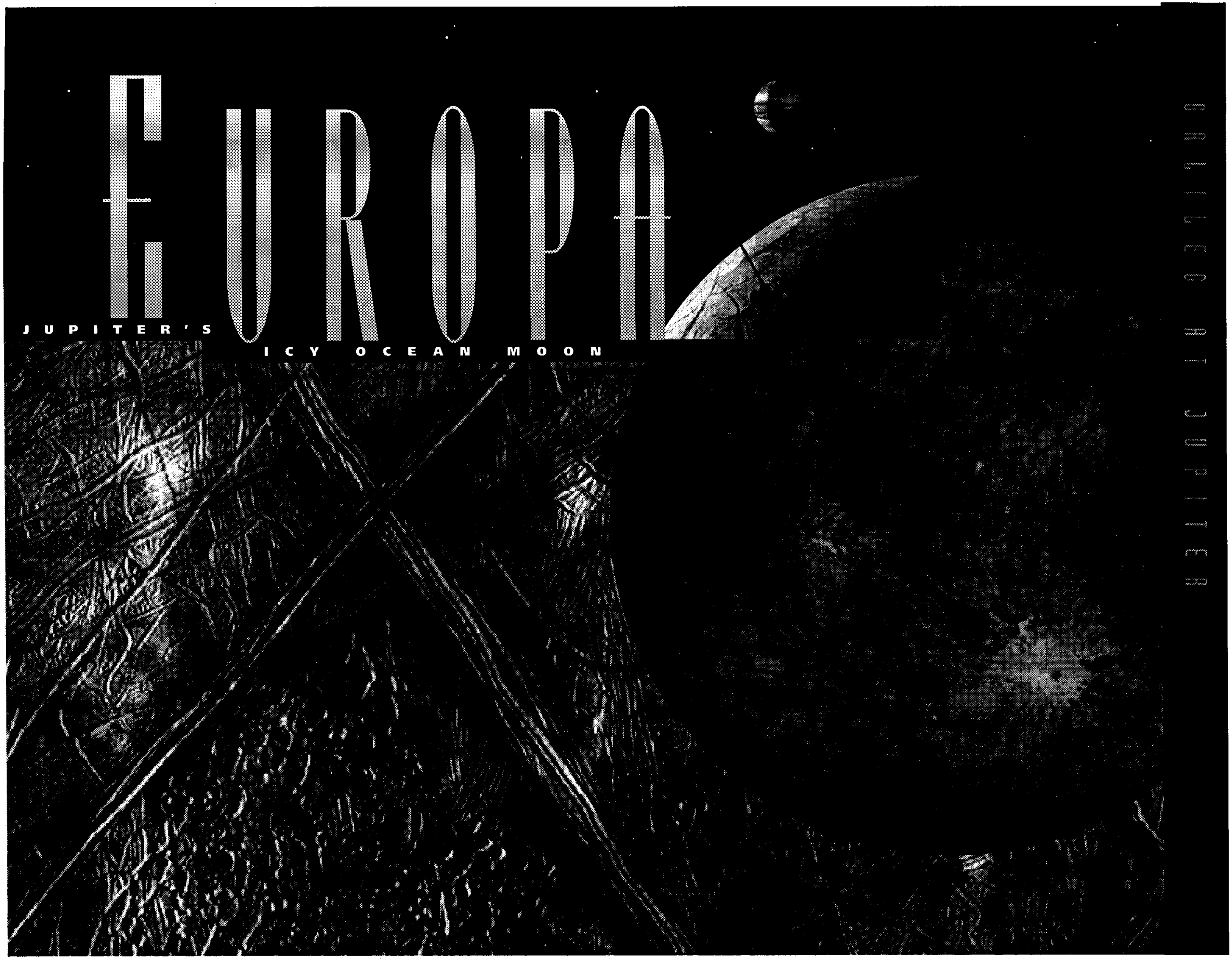
POSTER IS 25½ x 33"

DOC REVIEW



Europa — Another Water World?

Europa is a puzzle. The sixth largest moon in our solar system, Europa confounds and intrigues scientists. Few bodies in the solar system have attracted as much scientific attention as this moon of Jupiter because of its possible subsurface ocean of water. The more we learn about this icy moon, the more questions we have. Because the nature of science is to ask questions, we cannot resist the mystery of Europa and its potential for possessing an **ocean**.

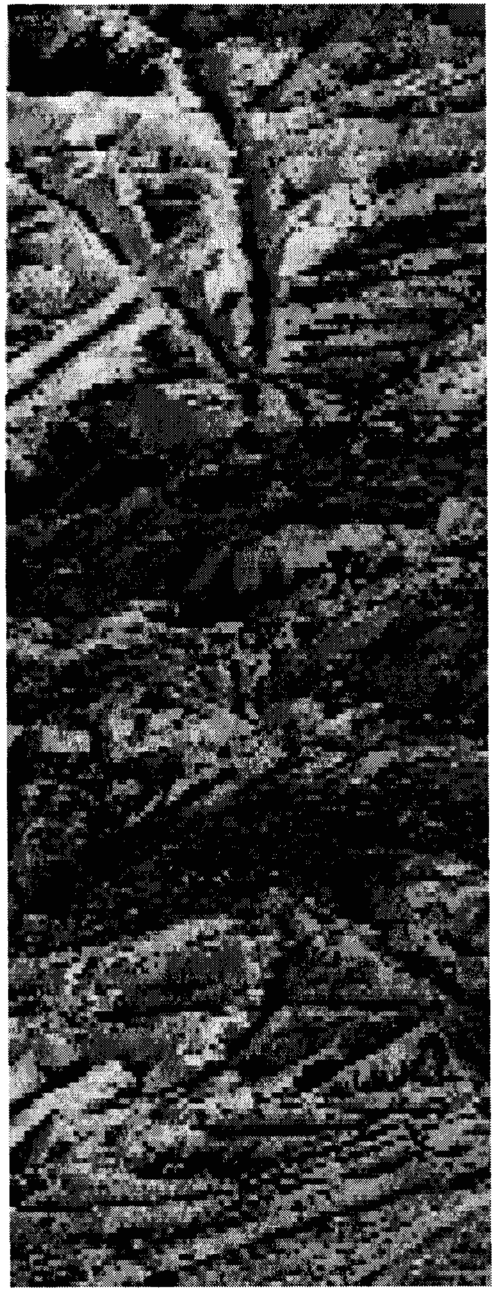
The United States sent two spacecraft, Pioneer 10 and 11, to **Jupiter** in the early 1970s. No one knew if a spacecraft could survive a flyby of Jupiter, but the Pioneers did survive, and they sent back valuable information for the next space mission. However, the Pioneer photographs of Jupiter's largest moons were fuzzy and dim. The twin Voyager spacecraft flew by Jupiter and its moons in 1979, giving us our first close-up view of Europa. Voyager pictures showed pale-yellow icy plains with red and brown mottled regions. Adding "false color" blue revealed many fascinating details (the front of this poster shows a false-color Europa). Long cracks run for thousands of kilometers over the surface. On Earth, these cracks would indicate such features as tall mountains and deep canyons. But none of these features are higher than a few kilometers on Europa, making it one of the smoothest objects in our solar system.

If we look at the surface more closely, as we have with the instruments on the **Galileo** spacecraft, orbiting Jupiter since 1995 (see "Galileo Tours" panel), we see some fascinating features. Europa looks like broken glass that is repaired by an icy glue oozing up from below. Low ridges, straight and curved, crisscross the surface. Flows and fractures, pits and frozen "puddles" — all hint at a unique geologic history. Large circular features could be the sites of impacts or the result of upwelling of material from beneath the surface. Making sense of this chaotic landscape is a challenge to planetary scientists.

Despite the chaos of its surface, Europa is probably the kind of puzzle that science can solve. Some of our questions are: "How old is the surface? How were the cracks and other features made? What is under the **ice**?" To answer them, we collect data and make careful observations, applying what we know about geology, physics, and chemistry. Geologists figure out the age of a surface by counting the impact craters formed where comets, meteorites, and other debris hit the surface. Earth's Moon has young and old craters literally everywhere, which tells us that it has been geologically inactive for more than a billion years. Earth has been impacted at least as many times as the Moon, but Earth's surface has been smoothed by active geological processes such as plate tectonics and volcanic flows, and by constant weathering. Like our Moon, Jupiter's satellites Ganymede and Callisto are heavily cratered — evidence of very old and inactive surfaces. On Europa, however, only a few large craters have been identified. Unless Europa has somehow avoided these impacts (which is unlikely), relatively recent events must have smoothed over the craters.

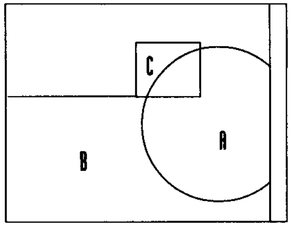
Looking at the pictures from Galileo, we see evidence of geologic action on Europa. Small blocks of crust float like icebergs over an invisible sea (see "What Do the Pictures Mean?" panel). Some blocks are tilted, others rotated out of place. Dark bands of ice and rock spread outward from a central ridge (see "Europa Geology Jigsaw Puzzle" panel). What is the cause for this activity? In a gravitational tug of war of incredible dimensions, Europa is pulled in different directions by Jupiter and by the planet's other moons in a process called tidal flexing. Over one Europan day, it stretches and compresses up to several tens of meters. The outer surface of Europa is a rigid sphere. Imagine Earth covered by a blanket of ice that traps the oceans below. In the course of a day, these oceans rise and fall. This is what happens to Europa. The flexing of Europa's surface continues until the brittle crust cracks. We don't know what happens when the crust fractures. The process may be slow and steady, advancing only centimeters at a time — or, it may cause ice volcanoes or geysers to erupt violently, showering the surface with material from below.

Another interesting possibility arises from this tidal flexing of Europa. Heat generated by the expansion and contraction may be enough to melt part of the crust underneath the surface, creating lakes or oceans below. The possibility of liquid water just below Europa's surface naturally leads to the question of whether life could have evolved there. Scientists have discovered marine life on Earth that thrives in the deep ocean near hydrothermal vents. This discovery provides us with a model for how similar organisms might survive on Europa. However, liquid water is just one of life's key ingredients. Many other factors, including organic material and a continuous energy source, must be present. Even if there is no ocean currently on Europa, one may have existed in the past, perhaps leaving fossilized remains to be found by a future mission.



Europa at Highest Resolution. *During its 12th orbit around Jupiter, on December 16, 1997, Galileo made its closest pass to Europa. This image was taken from a distance of only 560 kilometers above the surface. The features at the bottom of the image are much closer to the spacecraft than those at the top, because the image was taken at a highly oblique angle — as though one were looking out of an airplane window. Many bright ridges can be seen, with dark material in the low-lying valleys. In the center, the regular ridges and valleys give way to a darker region of jumbled hills. The image area is about 1.8 kilometers wide. The smallest detail that can be seen is 12 meters, about the size of a schoolbus.*

What Do the Pictures Mean?



A "False Color" Globe

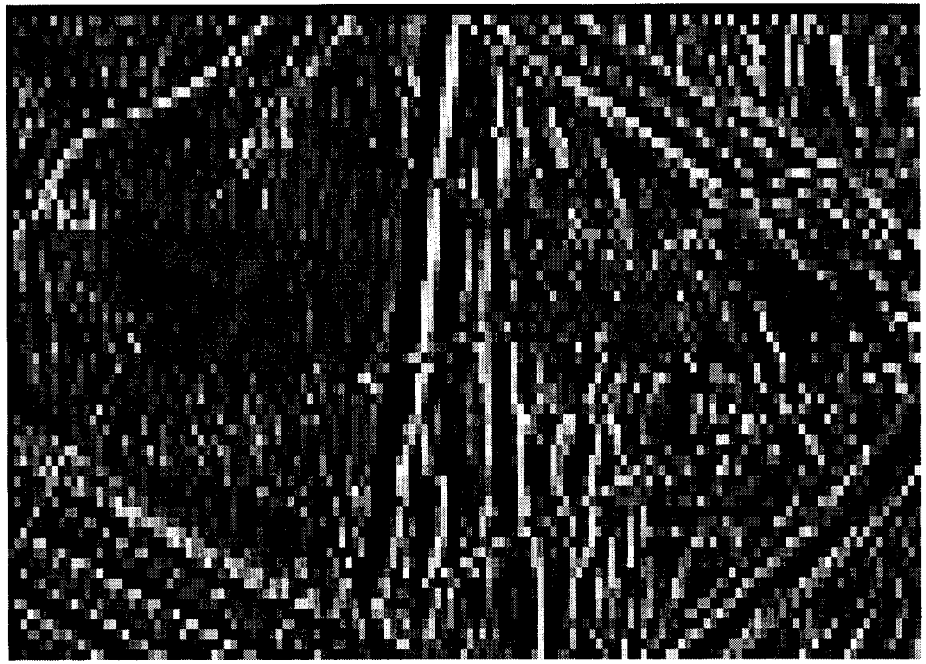
Europa is shown on the poster front in false color (Europa's true color is pale yellow). Shades of blue represent different sizes of the ice grains on the surface: dark blue shows coarse grains; lighter blue represents fine grains. Brown areas are contaminated with rocky material that came up from the interior or that was deposited from comets striking Europa. Because Europa always keeps the same face towards Jupiter, the side shown in this image is always "trailing" — the side you see if you could follow behind Europa in its orbit. The bright feature with a dark spot (lower right) is an impact crater about 50 kilometers in diameter. The ridges that form an "X" (right, just above center) are shown in detail in the enlarged "ice rafts" image. This image was taken by the Galileo spacecraft on September 7, 1996, from a distance of 677,000 kilometers.

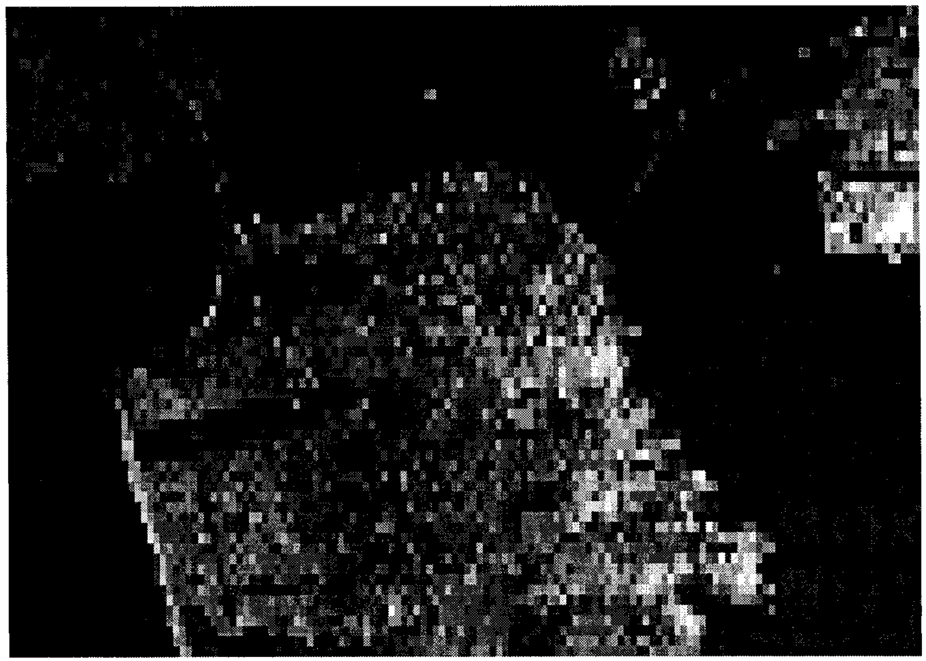
B Ice Rafts

Two large ridges that cross Europa's trailing face form an "X" that marks the spot for compelling evidence of a recent ocean underneath the icy surface. "Ice rafts," seen just under the crossing point, are blocks of ice the size of cities that appear to have broken and drifted apart. Scientists believe that a liquid or soft solid underneath the surface forced this movement of the ice. The remarkable lack of craters implies that the surface is geologically young. The image combines data from three flybys of Europa (September and December 1996, and February 1997). This image is in false color, allowing us to see different characteristics — bright white represents younger deposits, reddish areas are associated with internal geologic activity, and blue corresponds to older icy plains.

C Galileo Over Europa

The three main focuses of the Galileo Europa Mission (GEM) are illustrated in this artist's conception. Viewed from above Europa, Galileo makes a close flyby over the moon's cracked, icy surface, representing the studies done during first 14 months of GEM. The spacecraft points its instruments at Europa while communicating with Earth, which would appear near to the Sun as seen from Jupiter. Later in the mission, Galileo observes the great storms on Jupiter that sweep across the face of the giant planet. In the meantime, Galileo lowers its orbit closer and closer to the moon Io, and finally flies about 500 kilometers above one of Io's active, sulfur-spewing volcanoes.





The "Puddle" and the Bridge. *These two photographs show areas similar in size (13 by 18 kilometers) and resolution. (Resolution is related to the size of the smallest object that can be seen.) The top image was taken from a distance of 2,500 kilometers and shows a close-up of a region on Europa that is a strong indicator for a subsurface ocean; the bottom photo shows the San Francisco Bay Area with the Golden Gate Bridge at the top, connecting San Francisco to the Marin Peninsula. The smooth "puddle" in the image of Europa resulted from surface water that was liquid and then refroze. The crater in the middle of the frozen puddle was caused by a meteorite impact; the puddle might have formed as water melted from the heat of the impact or when water bubbled up from below. The puddle is about 3 kilometers across — the Golden Gate Bridge could almost reach across it. Both images show details as small as 52 meters, smaller than city blocks. Galileo took the Europa image on December 19, 1996.*

Europa Geology Jigsaw Puzzle

TARGET LEVEL: Middle School **TIME:** One 40-minute class period

MATERIALS: Each student needs 2 copies of the "Wedges" image, one printed on card stock, plus colored pencils and scissors. To download image, go to — http://www.jpl.nasa.gov/galileo/sepo/education/europa/images.html

Although the surface of Europa is frozen solid, liquid water may exist underneath as lakes or even an ocean. Pictures taken by the Voyager and Galileo spacecraft show areas of the surface where large plates of ice have apparently broken apart and moved away from each other. Some have even twisted and rotated. The easiest way for these movements to occur is if the plates are floating on water, just like ice floes that fracture and shift in the polar seas on Earth. If the plates can be fit back together like a jigsaw puzzle, with their edges matching up neatly, it will provide strong evidence that the material beneath them was once liquid, or at least warm, slushy ice. Let's try it and see!

1 Geologic Mapping

Look at the "Wedges" image to the right. Differences in surface texture, color, or shading show us that different regions are made of distinct materials, formed in unique ways, or created at different times. Making a geologic map can show these differences. Using the copy of the "Wedges" image that was printed on card stock, identify the three major areas that have different texture or shading. Ignore the small, narrow ridges. Lightly color each of the three surface types using a different color, even if they are not next to each other (for example, color all smooth, bright areas light green). When you are done, each color on your map will represent a unique geologic unit.

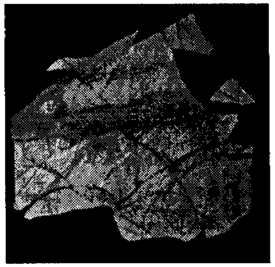
2 Determining Relative Age

Now that you have made a geologic map of the area, can you figure out which unit is oldest and which is youngest? One way to determine relative age is to look for crosscutting relationships. Like a cake that is sliced, the surface may be broken by a fracture or a fault. A unit (or slice) that cuts through the surface is always newer (younger) than the surface itself. Using the color as the name for each geologic unit, make a list of the units from oldest to youngest, according to the colors you have assigned to them.

3 Reconstructing the Landscape

Now you will rebuild the landscape to see how it looked at different times in the past. Using scissors, carefully cut up your map into the geologic units you identified. Each piece should contain one color only. When you are done, place the pieces back together in front of you. Using your "age" list, carefully remove from your map those pieces that belong to the youngest unit. Can you fill the empty space by pushing the remaining units towards each other? Do any features match up now that were once separated by the youngest unit? The surface you have created represents Europa at some time in the past.

Remove the pieces for the next youngest unit and shift the remaining pieces to fill the gaps. What types of motion were required this time? Do any features match up again? Compare this "original landscape" (see the sample at right, beneath the large "Wedges" image) to your uncolored, uncut "Wedges" image. As a final step, reverse the process and "rebuild" the surface of Europa one unit at a time. This should give you a clearer picture of some of the types of geologic materials, forces, and events that are responsible for shaping Europa's interesting surface.



Europa "Wedges." *This image of Europa shows a region where large wedge-shaped bands crisscross the surface. Symmetric ridges within the dark bands suggest that the crustal plates on either side have fractured and moved apart, while the spaces between the plates filled in with darker material from below. This process appears to be similar to the one that causes spreading centers in the ocean basins on Earth: molten rock from Earth's interior oozes upward through the separating sea floor and creates new crustal rock. The image was taken by Galileo from a distance of 40,973 kilometers on November 6, 1996. The area is about 238 by 225 kilometers, or about the distance between Los Angeles and San Diego, California. (The straight black line represents missing data.) Right: Sample of "original landscape."*

Questions

1 Given the types of motion you used to reconstruct the Europan landscape, how would you describe the physical properties of the material beneath the surface — rough, smooth, sticky, slippery, or .... ?

2 Explain how the youngest geologic units you identified might have formed — that is, where did the material come from? Give the evidence for your answer.

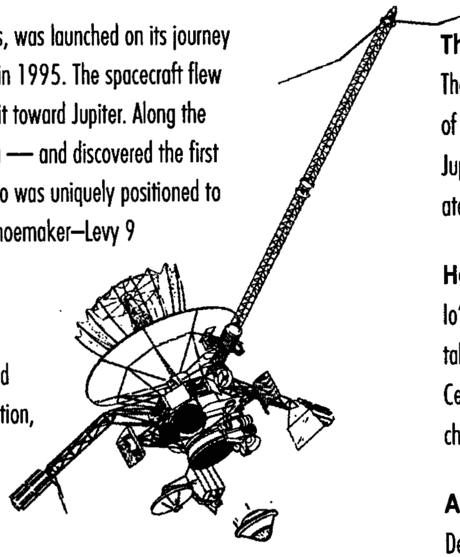
Note: This activity is available in electronic form on the World Wide Web at http://www.jpl.nasa.gov/galileo/wedges

Galileo Tours

Jupiter is the gaseous giant of our solar system — 1,400 times the size of Earth, and over half a billion kilometers away. Jupiter has a composition that is a lot like the early solar system. It is surrounded by thin rings made of dust-sized particles, has 16 moons, and has a dense fluid core that generates a powerful magnetic field. Galileo Galilei pointed a telescope at Jupiter in 1610, and discovered its four largest moons circling the planet. These four moons — Io, Europa, Ganymede, and Callisto — became known as the Galilean satellites. This discovery that objects orbit bodies other than Earth revolutionized people's thinking about how the solar system works.

The Galileo spacecraft, named in honor of the scientist and his discoveries, was launched on its journey to Jupiter from the Space Shuttle Atlantis in 1989 and arrived at Jupiter in 1995. The spacecraft flew by Venus once and Earth twice, using both planets' gravity to accelerate it toward Jupiter. Along the way, Galileo took the first-ever close-up images of an asteroid — Gaspra — and discovered the first known satellite of an asteroid: the asteroid Ida's tiny moon Dactyl. Galileo was uniquely positioned to photograph an astonishing event in July 1994 — the crash of Comet Shoemaker–Levy 9 (actually a string of 23 fragments) into Jupiter's atmosphere.

Upon arrival at Jupiter, Galileo's probe, released from the spacecraft about 5 months before, plunged into the planet's atmosphere and relayed to the orbiter a Jovian weather report on temperature, pressure, composition, winds, and lightning, while Galileo began its 2-year Prime Mission orbital tour.



GALILEO'S PRIME MISSION TO THE JOVIAN SYSTEM
OCTOBER 18, 1989–DECEMBER 7, 1997

Launched from Space Shuttle Atlantis	October 18, 1989
Atmospheric Probe Released	July 13, 1995
Arrival at Jupiter and Probe Entry	December 7, 1995
Probe Life — Atmosphere Penetration	59 minutes — 200 km penetration
Orbital Tour	December 7, 1995 – December 7, 1997
Number of Orbits	11
Closest Approach	261 km, Ganymede, September 6, 1996
Total Distance Traveled	4,044,600,000 km
Total Data Returned	2.4 gigabits (orbiter); 3.5 megabits (probe)
Number of Images Returned in Tour	1,645

Galileo Discovers — Orbital Tour Highlights

Thunderstorms on Jupiter

We know that Jupiter is made mostly of hydrogen and helium, with clouds of methane, ammonia, and water. Scientists were surprised when the Galileo probe found much less water than expected in the top clouds of Jupiter. But later, the instruments on the orbiting spacecraft confirmed that there are both dry and wet regions on Jupiter. In some large areas, such as the probe entry site, air descends and becomes as dry as the air in Earth's Sahara desert. In other areas, the air rises and the water in it condenses into thunderstorms many times larger than storms on Earth.

The Source of Jupiter's Rings

The Voyager spacecraft were the first to see mighty Jupiter's thin, dusty rings. The rings are visible only from the side of the planet facing away from the Sun. Scientists used Galileo data to show that the rings are made of bits of Jupiter's tiny innermost moons — Metis, Adrastea, Amalthea, and Thebe. Comets and meteorites, greatly accelerated by the huge pull of Jupiter's gravity, strike the little moons with explosive impacts, blasting bits from the surfaces.

Hot, Active Volcanoes on Io

Io's volcanoes, discovered by Voyager 1 in 1979, result from high tides (100 meters) in the fiery moon's solid surface. By taking Io's temperature with Galileo's instruments, scientists now know that some of Io's volcanoes (at 1800 degrees Celsius) are hotter than those on Earth. Galileo's instruments have also spotted many changes on Io's surface. Some changes occurred over years while others, including one area the size of Arizona, occurred in only about 5 months!

A Possible Ocean on Europa

Despite being 16 times smaller than Earth, Europa has more water than is contained in all our oceans, lakes, and clouds. Galileo images revealed that in recent history (geologically speaking), it appears that Europa had a salty ocean underneath its frozen surface. Ice "rafts" the size of cities appear to have broken and drifted apart, a frozen "puddle" smooths over older cracks, warmer material bubbles up from below to blister the surface, and a remarkable lack of craters shows the surface to be relatively young.

Ganymede's Own Magnetic Field

Tidal forces resulting from the tug-of-war between the immense gravity of Jupiter and its largest moons cause surprising results on the solar system's biggest moon, Ganymede. Galileo revealed that Ganymede has its own magnetic field — the first moon known to possess one. A molten core of iron or iron sulfide generates Ganymede's magnetic field.

An Ocean Inside Callisto, Too?

Scientists now have evidence that there may be an ocean underneath Callisto's crust, too! We don't see cracks or other features on the surface that might indicate a liquid underneath is changing the surface, so why do we think an ocean could be there? The "fingerprint" of this hidden ocean is a magnetic field around Callisto, detected by Galileo. It appears to result from Jupiter's hugely powerful magnetic field sweeping through a subsurface salty ocean, creating electric currents in the ocean that, in turn, generate a magnetic field around Callisto.

A Real "GEM" — The Galileo Europa Mission

The science results from Galileo during the originally planned Prime Mission at Europa were more fascinating and mysterious than we ever imagined. With a possible water ocean under a cracked, icy surface, Europa made us want to know more! The Galileo Europa Mission, or GEM for short, is a 2-year, low-cost extension through the end of 1999 of Galileo's exploration of the Jupiter system, consisting of an additional 14 orbits around Jupiter and flybys of its moons. To keep the mission low-cost, GEM has focused exploration objectives, divided into three phases.

1 Ice — Europa Campaign

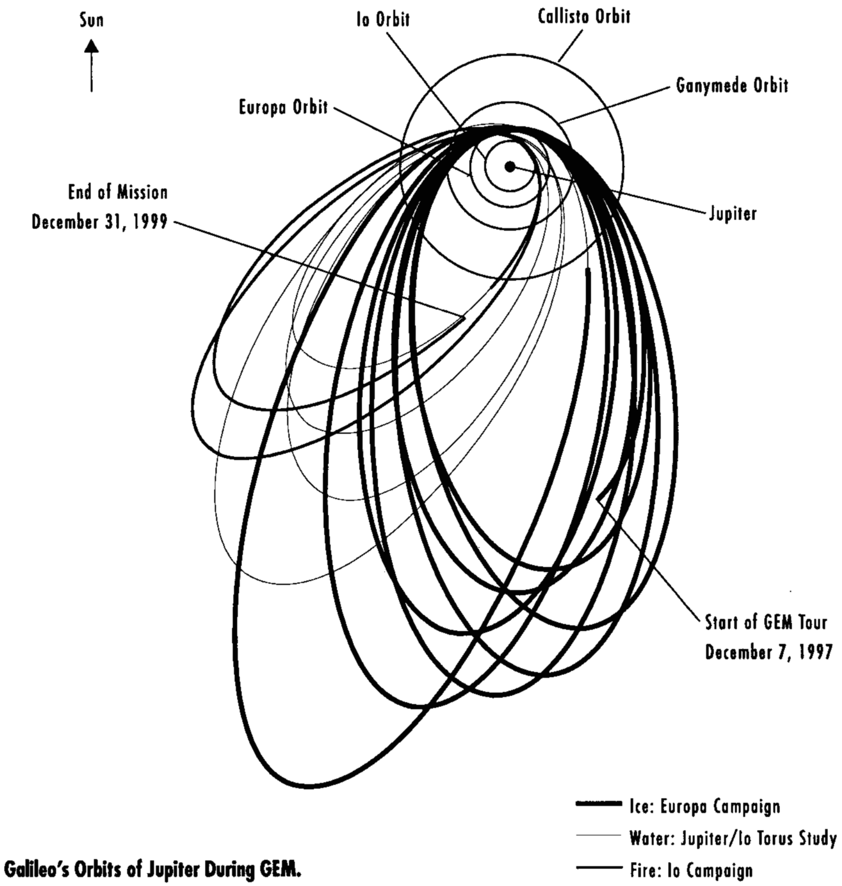
- Search for further signs of a past or present ocean beneath Europa's icy surface. GEM images will be compared with previous images to look for recent changes. The surface will be scanned for active ice volcanoes and other possible evidence of volcanoes.
- Determine if the magnetic signals nearest Europa are generated within the moon itself. (A flowing, salty subsurface ocean can generate a magnetic field.) Measure the pull of Europa's gravity, the thickness of the ice shell, and the depth of a possible ocean.

2 Water — Jupiter Water/Io Torus Study

- Study the storm and wind patterns in Jupiter's atmosphere, including thunderstorms.
- Map the distribution of water. Comparing Jupiter's atmosphere and weather with Earth's can help scientists understand our planet's more fast-paced weather changes.
- Map the density of the Io torus, a donut-shaped cloud of charged particles that rings Jupiter at Io's orbit.
- Use the gravitational pull of Callisto to halve the perijove (closest distance to Jupiter) of the spacecraft's orbit. This will prepare the spacecraft for its encounter with Io.

3 Fire — Io Campaign

- Obtain high-resolution images and a compositional map of Io.
- Sample a volcanic plume, flying 500 kilometers over the active volcano Pillan Patera.
- Determine if Io has a magnetic field. Assuming the spacecraft survives the harsh radiation environment, it will pass near the south pole at a distance of 300 kilometers.



Galileo's Orbits of Jupiter During GEM.

GALILEO EUROPA MISSION (GEM) — DECEMBER 7, 1997–DECEMBER 31, 1999	
Europa Campaign	December 16, 1997– May 4, 1999; 8 orbits
Closest Approach to Europa	201 km on December 16, 1997
Jupiter Water/Io Torus Study	May 5, 1999 – October 10, 1999; 4 orbits
Closest Approach to Jupiter	467,000 km on September 14, 1999
Io Campaign	October 11, 1999– December 31, 1999; 2 orbits
Closest Approach to Io	300 km on November 26, 1999
Total Distance to Be Traveled During GEM	278,300,000 km

We'll Be Back [Europa]!

Our curiosity about Europa has been only partially satisfied by the Galileo mission. In fact, the more answers we look for, the more questions we find. The extension of the mission for 2 years (the Galileo Europa Mission) shows just how intrigued we are by Europa. Fascinating images and unique data from the spacecraft have helped us to better understand this icy moon. However, what we have now is merely a snapshot compared to what we would like to know. To unravel its mysteries and complete the picture, we will need to return to Europa with new spacecraft.

Space exploration advances in a series of incremental steps. Each step is directed by unanswered questions, and each mission is designed with the technology available at the time of launch. One of the questions scientists debate is how long it has been since Europa was geologically active. The relatively small number of craters suggests that the moon's surface might be very young. Another question is whether heat generated by tidal flexing created a liquid ocean beneath the moon's icy crust (see "A Possible Ocean on Europa" on the "Galileo Discovers" panel). Galileo's instruments have given us enough information to ask these questions. But Galileo's trips past Europa last for just a few hours at a time — it's not long enough to get the information needed for the final answers.

The next step in our exploration of Europa is the Europa Orbiter mission, planned for launch from Earth in November 2003 for an arrival at Jupiter in August 2006. The spacecraft will spend 20 to 26 months orbiting Jupiter, performing short flybys of Europa, and will then change its orbit to encircle Europa itself and study the moon intensively for 1 month. During that time, the spacecraft will take continuous measurements of the moon's surface, atmosphere, and magnetosphere, but this part of the mission is limited to 1 month because of the damaging high levels of radiation near Jupiter. The Europa Orbiter will also measure the changes in Europa's shape as the moon moves in its orbit around Jupiter. If the crust is solid ice, changes caused by tides will be very small, perhaps only a few centimeters. On the other hand, if the surface moves by tens of meters, it is likely that a liquid ocean exists beneath the surface.

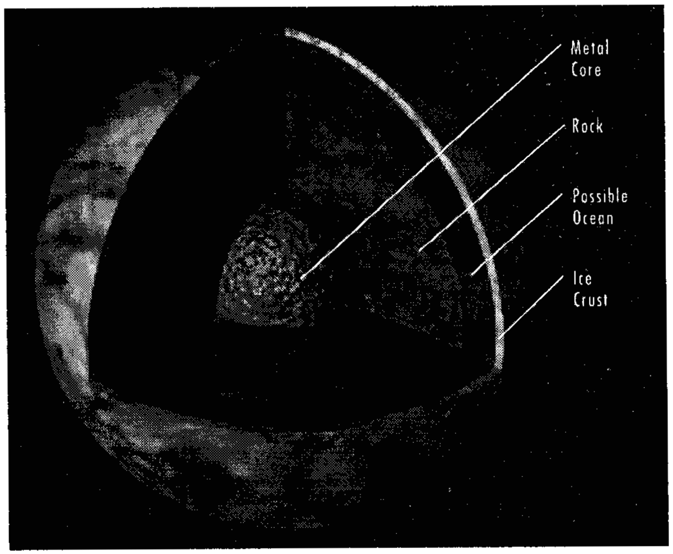
Scientists would also like to know about Europa's interior. Does the crust have the same density from top to bottom? Does it change abruptly from ice to water, or does it transition gradually from hard ice, to "soft" ice, to water? To answer these questions, the Europa Orbiter will use radar to look through the ice and determine how the crust changes with depth. As the spacecraft flies overhead, it will measure how different areas of Europa pull on the spacecraft. The amount of "pull" at each location depends on the mass between the moon's surface and its center. By comparing gravity data from many different locations, scientists hope to construct a three-dimensional view of the interior of Europa.

We learned from Galileo's instruments that several sizes of water-ice grains exist on Europa's surface. But we still do not know much about the reddish-brown material that covers much of the landscape. It may have oozed onto the surface through the many cracks in the ice, or it could be material derived from objects that impacted the surface. It may even contain organic compounds. Other future missions to Europa may include a lander or rover to collect and analyze samples of Europa's surface. A lander or rover could also measure movements of the icy crust — like earthquakes on Earth, there might be "Europa-quakes."

If an ocean exists beneath Europa's crust, how could we explore it? One idea is to send a lander to drill through the ice and release a remote-controlled miniature submarine equipped with lights and cameras. The submarine would act as our "eyes," swimming beneath the icy crust. Scientists are developing robotic explorers like this that will be used on Earth to study places like ice-covered Lake Vostok in Antarctica and life near the undersea volcanic vent Lo'ihi in Hawaii.

Under Europa's Ice. *This artist's rendering depicts a remotely controlled submarine-like robot taking pictures beneath Europa's crust.*

Ideas like these are being discussed by scientists as they strive to uncover the mysteries of Europa, and the space program will consider each proposed mission based on its merits and likelihood of success. Space exploration is for all humanity. If you could design a mission, what would you want to know about Europa? How would your space mission try to answer your questions? What new technologies can you imagine developing in the next millennium that might be used to explore Europa? Further, in-depth exploration of Europa will be unfolding in the next decade and will be an exciting adventure to follow.



Inside Europa. *Scientists have "peeled" Europa to get an idea of its structure. The interior characteristics are based on gravity and magnetic field measurements made by Galileo. Europa's radius is 1,565 kilometers — not much smaller than the radius of Earth's Moon. Europa has a metallic (iron and nickel) core surrounded by a thick shell of rock. The rock layer, in turn, is surrounded by a shell of water in ice or liquid form. The top layer of the water–ice shell is bright white to indicate that it may differ from the water or ice just below it. Galileo's images of Europa suggest that a liquid water ocean might be just below an ice layer. However, the evidence is also consistent with the existence of a past water ocean, and so it is not certain that Europa still possesses a liquid water ocean.*

Europa Facts

BIOGRAPHY OF A MOON

Discovery	January 7, 1610 by Galileo Galilei in Padua, Italy
Named for	Companion of Roman mythological god Jupiter
Surface composition	Mostly water ice
Visual albedo†	0.64
Height of tallest known feature	900 m
Diameter	3,130 km
Average distance from Jupiter	670,900 km
Average distance from the Sun	5.203 AU*
Rotational period (Time to turn once on its axis)	3.55 Earth days
Orbital period (Time to orbit Jupiter)	3.55 Earth days
Orbital eccentricity (The roundness of the orbit)	0.009
Orbital inclination (The angle of Europa's orbit compared to Jupiter's equator)	0.470 deg
Speed in orbit	13.74 km/sec
Mass	4.80×10^{22} kg
Surface gravity (Earth = 1)	0.133 (about 2/15 of Earth's gravity)
Density	2.99 g/cm^3
Escape velocity (How fast an object must travel to escape Europa's gravity)	2.02 km/sec

† Albedo = reflectance (brightness) of a surface: for a white surface, about 1; for a black surface, about 0.

* AU = astronomical unit: 1 AU is the mean distance between Earth and the Sun (about 149,600,000 km).

HOW BIG, HOW FAR, HOW FAST? COMPARING EUROPA, THE MOON, EARTH, AND THE TOWER OF PISA

Diameter at the equator	**Europa**	**3,130 km**
	Moon	3,475 km
	Earth	12,756 km
	Leaning Tower of Pisa*	1.55×10^{-2} km
Distance	**Europa to Jupiter**	**670,900 km**
	Moon to Earth	384,400 km
	New York to Pisa, Italy	6,900 km
Rotational period	**Europa**	**3.55 Earth days**
	Moon	27.32 Earth days
	Earth	1.00 Earth days
Orbital eccentricity — how round it is (circle=0; line=1)	**Europa**	**0.009**
	Moon	0.055
	Earth	0.017
	Leaning Tower of Pisa*	0.36
Tilt of the axis of rotation — relative to the orbit	**Europa**	**3.12 deg**
	Moon	6.68 deg
	Earth	23.45 deg
	Leaning Tower of Pisa†	5.60 deg
Mass	**Europa**	**4.80×10^{22} kg**
	Moon	7.35×10^{22} kg
	Earth	597.50×10^{22} kg
	Leaning Tower of Pisa	2.94×10^{-15} kg
Acceleration of gravity at the surface	**Europa**	**1.30 m/sec^2**
	Moon	1.62 m/sec^2
	Earth	9.80 m/sec^2
Density	**Europa**	**2.99 g/cm^3**
	Moon	3.34 g/cm^3
	Earth	5.52 g/cm^3
	Leaning Tower of Pisa°	2.50 g/cm^3
Volume of water	**Europa**	**2.90×10^{9} km^3**
	Moon△	7.15 × 10[illegible] km^3
	Earth	1.37 × 10[illegible] km^3

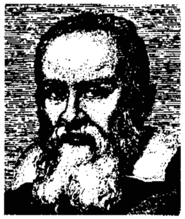
At 100 km/hr, it would take 4.11 Earth days to go around Europa; 4.55 Earth days to go around our Moon; 16.70 days to go around Earth; and 1.7 sec to run around the tower.

BARS BEING REDONE

If your weight (mass) is 50 kg on Earth, you'd weigh 2/15 of that on Europa and 1/6 of that on our Moon. What would you weigh on Europa and on Earth's Moon? Gravity is weaker on these smaller bodies, so you could jump higher, too. On Earth, you might jump 0.5 m, but on Europa you could get up to 3.8 m, and as high as 3.0 m on our Moon!

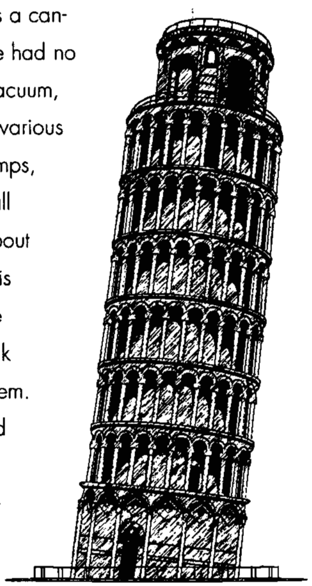
BARS ARE BEING REDONE

* Base of the tower
† Angle at which the tower leans
° Approximate density of marble as used in the tower
△ Estimates from Lunar Prospector, 1998



GALILEO TESTS GRAVITY

According to a legend, Galileo Galilei dropped objects of different weights from the Leaning Tower of Pisa to see whether heavy objects fall faster than lighter ones. Although the story is a myth, it shows the way people thought gravity worked. In fact, Galileo reasoned that gravity affects all things equally. In a vacuum, where there is no air resistance, a feather falls just as fast as a cannonball. But as he had no way to make a vacuum, he rolled balls of various weights down ramps, seeing that they all accelerated at about the same rate. This gave him the clue he needed to think through the problem. Galileo combined his observations with logical thinking to figure out the answer.



SIZING EUROPA

If you could place it there, Europa would fit neatly between the east and west coasts of the United States.

A Moon Called Europa

In 1609, Galileo Galilei was a respected scientist and teacher at the University of Padua in Italy. On a visit to nearby Venice, he learned that optical magnifiers in tubes were being constructed by Dutch eye-glass makers. Galileo was intrigued by these "spyglasses" and began building his own instruments, improving the optics for greater magnification as he went along. When he looked through his new instrument at a familiar heavenly body, our Moon, Galileo saw that what appeared to the unaided eye as a smooth, flat wafer in the sky was an object of substance and depth, with a rough, mountainous surface — it was another world. It was clear to Galileo that the new instrument represented a wonderful opportunity for science, and he began to use it as a telescope to examine the night sky.

Jupiter's Pinpoints of Light

Galileo began observing Jupiter on January 7, 1610. He saw four brilliant pinpoints of light around the planet and noticed that they changed positions in just a few hours. He wrote down his observations each night, and within a few days, he understood that these tiny "stars" were orbiting Jupiter — like a miniature solar system. He had seen the large moons, or satellites, of Jupiter. ("Satellite," meaning attendant or guard, was a term suggested by Johannes Kepler.) Galileo published his findings in March 1610 in a book called *Sidereus Nuncius*, or *Starry Messenger*, calling the moons Sidera Medicaea (Medicean Stars) I, II, III, and IV, honoring his patrons, the powerful Medici family of Florence, Italy.

A rival observer in Germany, Simon Marius, claimed to have seen the moons before Galileo did, but only began to make notes on December 29, 1609. As Galileo pointed out later, Germany was using an old-style calendar, while Italy had converted to the new-style, or Gregorian, calendar. December 29, 1609, in Germany corresponded to January 8, 1610, in Italy — the day *after* Galileo first recorded his observations of the moons.

What's In a Name?

While Galileo won credit for the discovery (the four large satellites are known today as the Galilean moons), his rival Marius won the naming game. In his 1614 publication *Mundus Jovialis* (*The World of Jupiter*), Marius proposed naming the "stars" after four Jupiter-related figures in classical mythology: "Three maidens are especially mentioned... Io, daughter of the River Inachus, Callisto of Lycaon, [and] Europa of Agenor. Then there was Ganymede, the handsome son of King Tros, whom Jupiter, having taken the form of an eagle, transported to heaven on his back, as poets fabulously tell.... I think, therefore, that I shall not have done amiss if the First [moon] is called by me Io, the Second Europa, the Third, on account of its majesty of light, Ganymede, the Fourth Callisto. ...This fancy, and the particular names given, were suggested to me by Kepler, Imperial Astronomer, when we met at Ratisbon fair in October 1613. So if, as a jest, and in memory of our friendship then begun, I hail him as joint father of these four stars, again I shall not be doing wrong."

Mythological Jupiter transformed himself into a bull and took Europa to the island of Crete, where she founded the Minoan civilization. The statue illustrates the journey; dolphins accompany Europa, while Cupid whispers in her ear.

Still, it was not until the mid-1800s that the names proposed for the moons by Kepler and Marius became popular. The tales of Jupiter, Io, Europa, Ganymede, and Callisto were also more well-known then than they are today. You can find the stories in any of the many translated versions of the Roman poet Ovid's *Metamorphoses* and in other works of Greek and Roman mythology.

More Resources

The Galileo Europa Mission World Wide Web site features an interdisciplinary way to bring classical literature and cutting-edge science together, and also helps students learn about the interior structure of the moon Europa — http://www.jpl.nasa.gov/galileo/europa

More! More! More! — Resources

Books

FICTION

- Clarke, Arthur C., (1968) 2001: A Space Odyssey, New American Library; (1982) 2010: Odyssey Two, Del Rey Books, Ballantine; (1987) 2061: Odyssey Three, Del Rey Books, Ballantine; (1997) 3001: The Final Odyssey, Del Rey Books, Random House

  The Odyssey series chronicles the relationship between humans and a mysterious alien object known as the Monolith. In 2010, the Monolith transforms Jupiter into a miniature Sun, allowing life to evolve on the once-frozen moon Europa.

- Ovid (43 B.C.–17 or 18 A.D.), Metamorphoses, R. Humphries, translator (1955), Indiana University Press

  A retelling of the original myth of Europa and Jupiter.

NON-FICTION

- Beatty, J. K., and A. Chaikin, editors (1990), The New Solar System, Third Edition, Cambridge University Press, Cambridge
- Beebe, R. (1997), Jupiter: the Giant Planet, Smithsonian Institute Press, Washington, D.C.
- Christiansen, E. H., and W. K. Hamblin (1995), Exploring the Planets, Second Edition, Prentice-Hall, Englewood Cliffs, New Jersey
- Greeley, R. and R. Batson, (1997), The NASA Atlas of the Solar System, Cambridge University Press, Cambridge, UK
- Murray, B. (1989), Journey Into Space: The First Thirty Years of Space Exploration, W. W. Norton, New York
- Sís, P. (1996), Starry Messenger, Farrar, Straus, Giroux, New York

Magazine Articles

- Carroll, M. (1996), "Sea-ice Ridges on Jupiter's Moon Europa?" Astronomy, vol. 24, April, p. 22
- Carroll, M. (1997), "Europa: Distant Ocean, Hidden Life?" Sky and Telescope, vol. 94, no. 6, p. 50
- Cowen, R. (1998), "Craft Eyes New Evidence of a Slushy Europa," Science News, vol. 153, no. 10, p. 149
- Kluger, J. (1998), "Snapshots from Europa," Time, vol. 151, no. 10, March 16, p. 60
- Milstein, M. C. (1997), "Diving into Europa's Ocean," Astronomy, vol. 25, no. 10, October, p. 38
- "Mysterious Moons" (1997), Time for Kids, April, p. 4
- Svitil, Kathy A. (1997), "Water World," Discover, vol. 18, no. 5, p. 86

Check out your local library for additional magazine and journal articles, books, and videos!
An in-depth list of references can be found at the JPL Project Galileo home page at —
http://www.jpl.nasa.gov/galileo/sepo/reference/biblio/biblio.html

World Wide Web Sites

EUROPA

- NASA/JPL Europa Focus Page — http://www.jpl.nasa.gov/galileo/europa
- NASA/JPL Galileo Europa Mission — http://www.jpl.nasa.gov/galileo/gem

GALILEO MISSION

- NASA/JPL Project Galileo Home Page — http://www.jpl.nasa.gov/galileo
- Galileo Education Page — http://www.jpl.nasa.gov/galileo/education.html

SOLAR SYSTEM

- Planetary Photojournal — http://photojournal.jpl.nasa.gov
- Welcome to the Planets — http://pds.jpl.nasa.gov/planets

GENERAL EDUCATION

- NASA Spacelink — http://spacelink.nasa.gov
- Solar System Exploration Education Forum — http://www.jpl.nasa.gov/forum
- JPL Education — http://www.jpl.nasa.gov/education

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Your evaluation and suggestions are vital to continually improving NASA educational materials.

Credits — *The Europa Geology Jigsaw Puzzle activity was adapted from: Tufts, B. R., R. Greenberg, R. Sullivan, and R. Papalardo, 1997, "Reconstruction of Europan Terrain in the Galileo C3 'Wedges' Image and Its Geological Implications," Lunar and Planetary Science Conference XXVIII, Houston, Texas, Lunar and Planetary Institute, pp. 1455–1456. The partial reconstruction ("original landscape") of the "Wedges" image appears in R. Sullivan et al. (1998), "Episodic Plate Separation and Fracture in Fill on the Surface of Europa," Nature, vol. 391, pp. 371–373. The sculpture depicted in "A Moon Called Europa" is "Flight of Europa" by Paul Manship; photograph by Mary Ann Sullivan.*

The Galileo mission is managed for the National Aeronautics and Space Administration (NASA) by the Jet Propulsion Laboratory, California Institute of Technology.

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